Annual Report for Year 2 (03/15/2007 to 03/14/2008)

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Applied Information Systems Research Program

Automated Identification and Characterization of Landforms on Mars

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Summary of objectives

The goal of this project is to use a fusion of methods from the fields of digital terrain analysis, computer vision, and machine learning to develop fully autonomous algorithms for identification and characterization of various landforms on Mars with emphasis on craters and valley networks. Such automation is necessary to provide the scientific community with the ability to process, analyze, and ultimately turn into knowledge a significant portion of the huge amount of spatially extended data collected by spacecrafts orbiting Mars. The project aims at developing robust, "production ready" algorithms, which utilize topographic data over traditionally used imagery.

Progress in Year 2

Cataloging craters from topographic data

During Year 1 we have concentrated on developing a core algorithm for identification and characterization of impact craters on Mars. This core algorithm is available at *cratermatic.sourceforge.net*. During Year 2 we have concentrated on constructing and executing scripts that, while using a core algorithm, would allow us to catalog craters > 3 km in diameter over the entire Martian surface. Because of memory requirements the surface of Mars needs to be tessellated into > 400 overlapping tiles, and the crater recognition algorithm identifies craters from each tile separately. We have achieved the final package by linking our core algorithm (written in C++) with WEKA machine learning software (open source) and ArcGIS package (commercial software). Our script performs a number of operations on each tile. It needs to project the topographic data into a projection assuring that craters are circular depressions, use our core algorithm to identify crater candidates, use WEKA to perform classification aimed at dividing craters from non-craters, and finally use ArcGIS to produce layers designed to show cataloged craters. Overall, our method has produced a catalog of about 100,000 craters. This catalog is a very significant tool for the planetary science community because, for the first time, it lists crater depths in addition to their sizes. Thus, using this catalog we can produce global maps of depth/diameter ratio a totally novel view of Mars that provides insights into surficial processes and spatial distribution of subsurface ice. We have reported on our findings at the 7^{th} *International Conference on Mars* (July 2007) and 39^{th} *Lunar and Planetary Conference* (March 2008). Fig. 1 shows spatial distribution of depth/diameter ratio for southern hemisphere of Mars showing intriguing pattern that is best interpreted in terms of the distribution of subsurface ice.

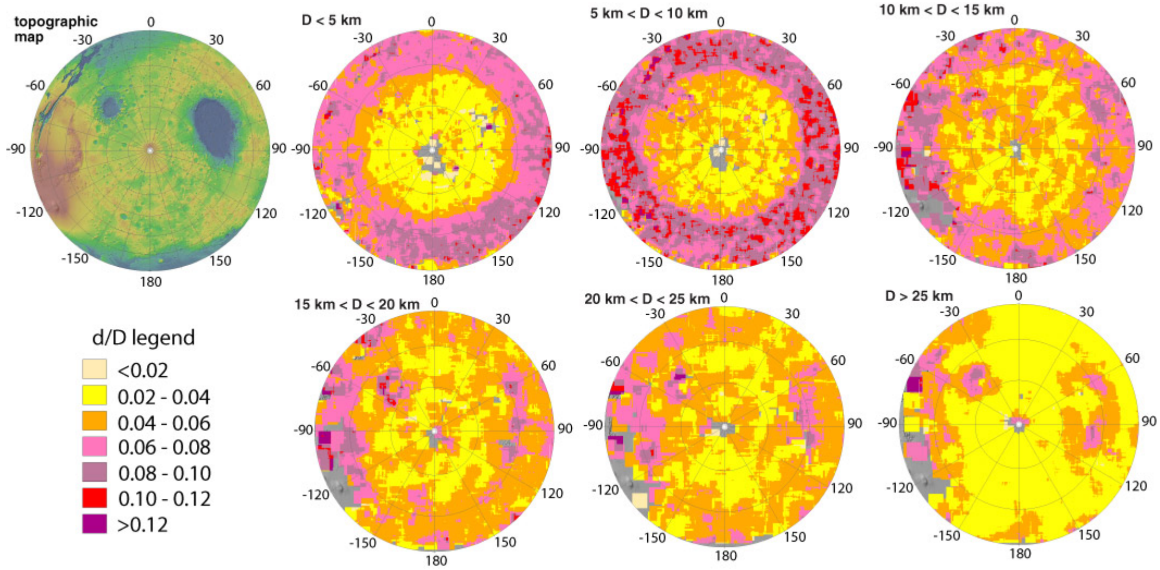

Figure 1: *Raster maps of spatial distribution of (d/D) in the southern hemisphere of Mars. All maps are shown in the Lambert azimuthal equal-area projection centered on the south pole. (A) The topographic map of the southern hemisphere is shown for reference. (B) - (G) Maps of (d/D) constructed for craters $D < 5$ km , 5 km $\leq D < 10$ km, 10 km $\leq D < 15$ km, 15 km $\leq D < 20$ km, 20 km $\leq D < 25$km, $D \geq 25$ km, respectively. Different colors correspond to different values of (d/D) as shown in the legend. Pixels that lacks sufficient number of craters in their neighborhood to calculate moving average are shown in gray.*

Cataloging craters from imagery data

During Year 2 we become aware (through contacts with members of the planetary science community) that there is a lot of interest in automated identification of sub-kilometer craters on Mars, as well as on other planets. Due to lack of high resolution topographic data our core algorithm cannot identify such small craters. Therefore, we have started to investigate a possibility of cataloging sub-kilometer craters from high resolution panchromatic images. Our approach uses shape filters to find the characteristic highlight and shadow regions of craters, after which the method matches these regions into possible crater candidates. Supervised machine learning is then applied to classify these candidates into craters and non-craters. In Year 2 we have developed a core algorithm for identification of sub-kilometer carters from images and started testing it on images taken by High Resolution Stereo Camera (HRSC) instrument on the Mars Express orbiter. These images have resolution of 12.5 m/pixels and we are able to identify reliably craters as small as 200 meters. Fig. 2 shows the basic concept behind our algorithm and a sample application. In this sample application we have achieved ~70 % accuracy rate. Our first results were reported at the *39th Lunar and Planetary Conference* (March 2008).

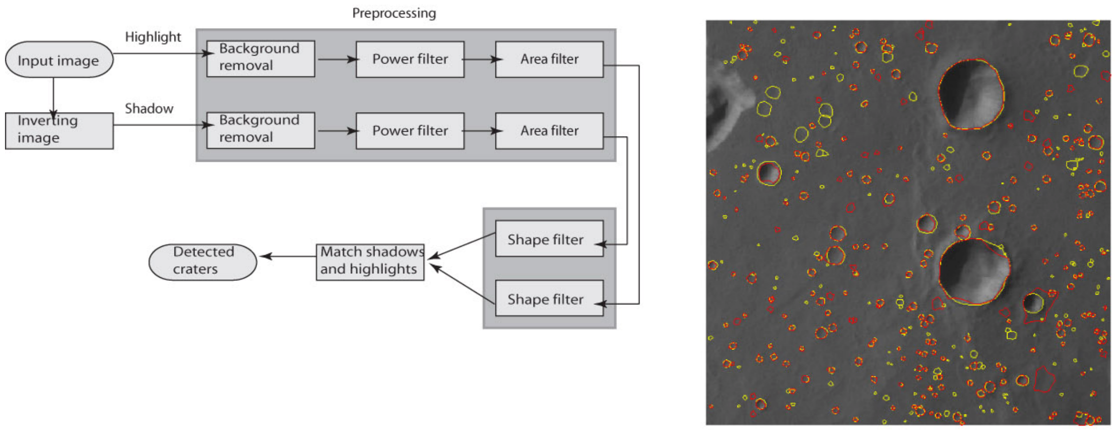

Figure 2: *(Left) Diagram illustrating the individual steps in our method for detecting sub-kilometer craters in images. (Right) A small segment of h0905_0000 HRSC footprint with resolution of 12.5 meters. Craters identified by our algorithm are shown in red, manually marked craters are shown in yellow.*

Mapping Valley Networks

In Year 1 we have developed a novel drainage delineation algorithm specially designed for mapping the Martian valley networks from digital elevation data. In Year 2 we have developed scripts to apply this core algorithm to map valley networks on the entire surface of Mars. Like in the case of craters, the memory requirements are such that Martian surface must be tessellated into overlapping tiles and each tile is processed separately. Our ultimate goal (not yet completed during Year 2) is to obtain a global map of valley network and a global database of such networks. Whereas, the map is intended to visually show the valleys (see Fig. 3) the database is intended for queries. For example Fig. 4 shows a query in which networks located within a specific geological unit, having at least three segments and no loops are selected. In addition, in Year 2, we have developed an implementation of our core, valley network extraction algorithm as a Web Service within a framework of GeoBrain. The purpose of this service is to provide everyone with the capacity to extract valley networks (or river systems) using our novel, morphology-based method without specialized software tools like ArcGIS or GRASS. Our Web Service can be test driven at http://65.123.203.154:8099/OnAS/.

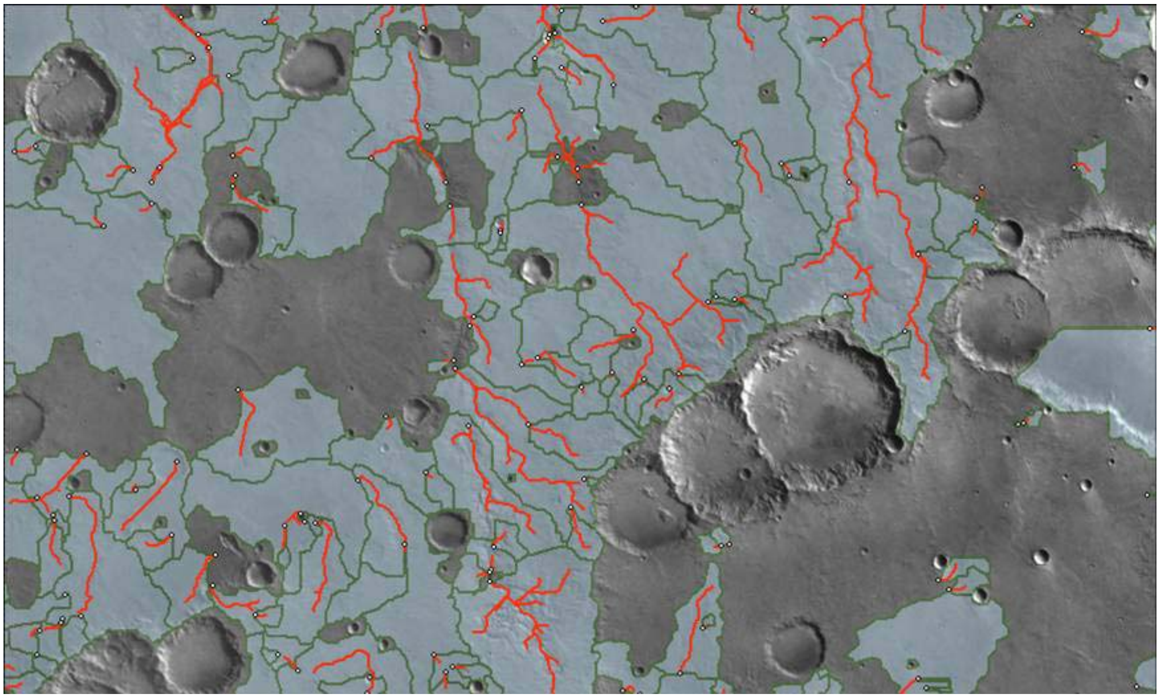

Figure 3: *A fragment of global map of valley networks on Mars. Red lines indicate valley networks. Green lines show boundaries of watersheds associated with each network. The map is superimposed on THEMIS mosaic.*

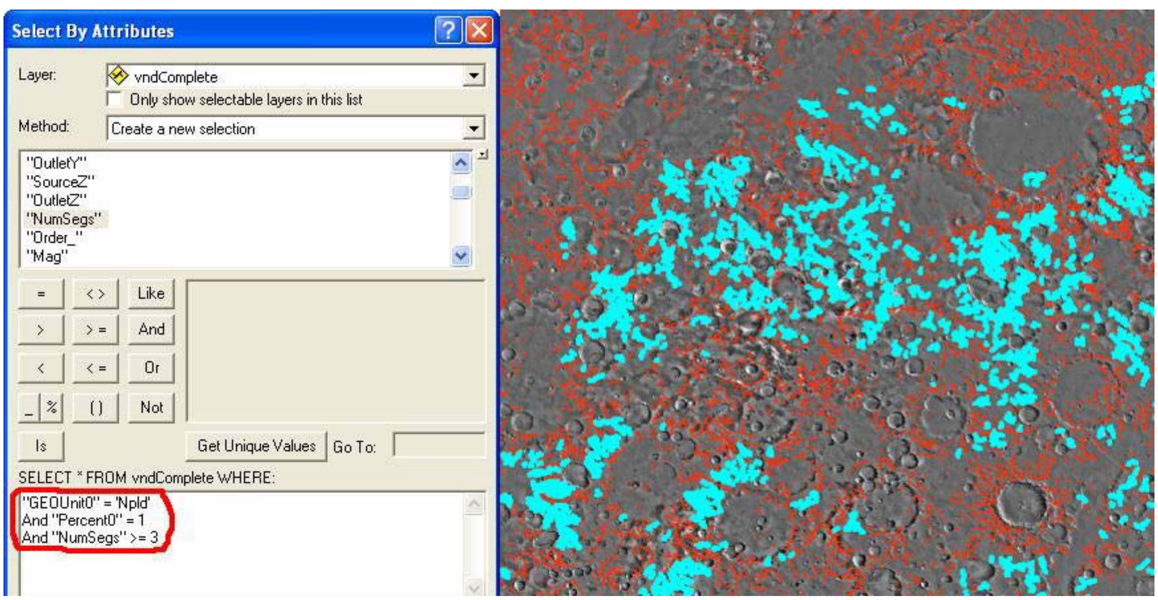

Figure 4: *Example of querying the global database of valley networks. Networks that are located within the Npldgeological unit, having at least three segments and no loops are selected and shown in blue.*

During the Year 2 we have also become aware that our algorithm for extraction valley networks on Mars has terrestrial application for regional mapping of drainage density.

The unique feature of our algorithm is its ability to handle variable drainage density. The available algorithms for mapping terrestrial streams (including the tool in ArcGIS) are not equipped to handle variable drainage density and produce spurious results in such cases. In the paper currently in press in *Geomorphology* we have demonstrated the advantage of our algorithm over other available algorithms for terrestrial applications (see Fig. 5)

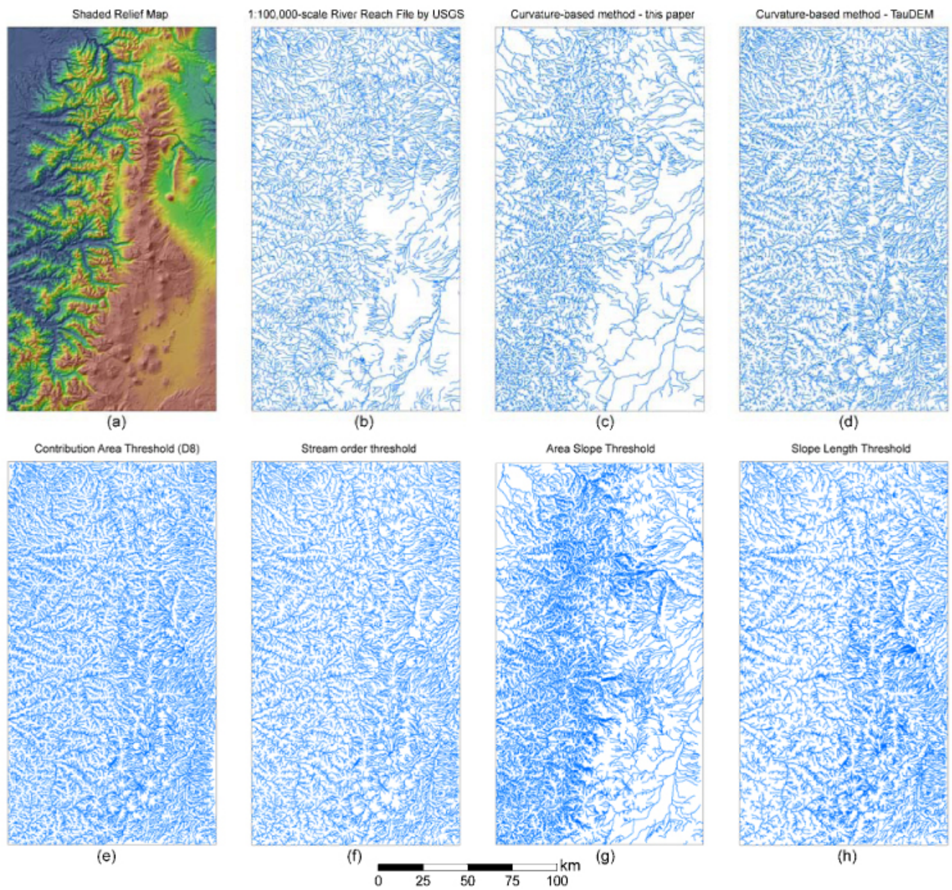

Figure 5: *Machine mapping of drainage in Cascade Range, Oregon (between -122.75°E and -121.31°E and between 43.31°N and 45.26°N, an area of roughly 117 km by 216 km.) (A) Digital elevation model. (B) Ground truth – a map of streams based on aerial photography. (C) Our method based on an algorithm developed for valley networks on Mars. ((D – H) Drainage extracted using existing delineation techniques.*

Publication:

- W. Luo, X. Li, I Molloy, and T.F. Stepinski (2008) Web Service for Extracting Stream Networks from DEM Data. To appear in 16^{th} International Conference on Geoinformatics, June 28-29 Guangzhou, China.
- R. Vilalta and T.F. Stepinski (2008) Pattern Validation in Machine Learning: A Case Study in Planetary Science (2008) to appear in Encyclopedia of Data Warehousing and Mining – Second Edition, J. Wang Edt. IGI Global.
- W. Luo and T.F. Stepinski (2008) Identification of Geologic Contrast from Landscape Dissection Pattern: An Application to the Cascade Range, Oregon, USA. Geomorphology, in press.
- T.F. Stepinski, R. Vilalta, S. Ghosh (2007) Machine Learning Tools for Automatic Mapping of Martian Landforms. IEEE Intelligent Systems Nov 2007. pp. 100-106.
- T. F. Stepinski, M. P. Mendenhall, and B. D. Bue (2007) Machine Cataloging of Impact Craters on Mars. submitted to Icarus.
- S. Ghosh, T. F. Stepinski, and R. Vilalta (2007) A Framework for Automatic Annotation of Planetary Surfaces with Geomorphic Labels, submitted to Machine Learning Journal.
- T. F. Stepinski, S. Ghosh, and R. Vilalta (2007) Machine Learning for Automatic Mapping of Planetary Surfaces. To appear in proceedings of Nineteenth Innovative Applications of Artificial Intelligence Conference, July 24-26, 2007, Vancouver, British Columbia.
- T. F. Stepinski and E. R. Urbach (2007) Mapping craters depths in Terra Cimmeria, Mars: Implications for spatial distribution of ground ice. 7th International Conference on Mars, July 9-13, Pasadena, California
- B. W. Luo, T. F. Stepinski,and R. Y. Qi (2007) Drainage Density and Controlling Factors in Cascade Range, Oregon, USA. To appear in proceedings of Geoinformatics 2007, May 26-28, 2007, Nanjing, China
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- T.F Stepinski and E.R. Urbach (2008) Raster Maps of Craters Depths in Southern Hemisphere of Mars: Potential Proxy for Spatial Distribution of Ground Ice. In Lunar and Planetary Science XXXVIX, Abstract # 1272
- T. F. Stepinski, W. Luo, and Y. Qi (2007) Precision Mapping of Valley Networks in Margaritifer Sinus, Mars. In Lunar and Planetary Science XXXVIII, Abstract # 1205
- Ghosh, S., T. F. Stepinski, and R. Vilalta (2007) Automatic Mapping of Martian Landforms Using Segmentation-based Classification . In Lunar and Planetary Science XXXVIII, Abstract # 1200
- T. F. Stepinski, M. P. Mendenhall, and B. D. Bue (2007) Robust Automated Identification of Martian Impact Craters. In Lunar and Planetary Science XXXVIII, Abstract # 1202